A new conductivity sensor for monitoring the fertigation in smart irrigation systems

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Abstract. The incorrect fertilization of the crops can cause problems in the environment and extra costs. A solution is the perform fertigation controlling the amount of fertilizer in the water. In this paper, we test different combinations of coils for determining the amount of fertilizer in the water. A coil is powered by a sine wave of 3.3 peak-to-peak Volts for inducing another coil. These sensors will be included in a smart irrigation tube as a part of a smart irrigation system based on the Internet of Things (IoT). The aim of this system is to detect different sorts of problems that can cause incorrect fertilization, which affects the sustainability of agriculture. This system can be used in different scenarios where tubes are used to irrigate. We present the performed test to evaluate the suitability of the created prototypes. At first, we test with different dilutions of NaCl (table salt) and after we tested by nitromagnesium (a fertilizer). We check that at the same salinity the induction value changes if it is found in water with NaCl or nitromagnesium. Of all the tested prototypes it is concluded that the prototype P2 is the most optimal.g/l Because there is a difference in the induced voltage between 0 and 45 g/ l of nitromagnesium of 3.79 V with a good correlation coefficient. In addition, the average error in the different samples tested in the verification test is 2.15%.

Keywords: Coils; Conductivity; Fertigation; Irrigation systems; IoT.

1 Introduction

Agriculture provides most of the food consumed worldwide today. It is estimated that 95% of the food consumed is produced directly or indirectly in the soil. A healthy soil for optimal growth of species must have a certain amount of microorganisms that transform inert matter, such as minerals into nutrients. To maintain an optimal relationship in the soil it is necessary that it has an optimal ratio of C: N (carbon/nitrogen) so that existing bacteria can provide nutrients to the crops, these two compounds being limiting in the soil [1].

Intensive agriculture is one of the main causes of soil degradation. This type of soil loses most of the nutrients, because of this intensive use of lands. Consequently, future plantations lack this support to produce optimal crops [2]. Due to this need for plants to maintain a correct balance of nutrients in the soil, the use of nitrogen fertilizers has increased to a large extent among farmers.

The use of these compounds has some risks, caused by undue fertilization, which leads to serious problems both in the quality of soil, by the loss of nitrogen-fixing microorganisms [3] , and in the environment, such as contamination of the soil, groundwater or the pollution of rivers by runoff [4]. Groundwater represents a source of fresh water of great importance for human beings, due to its use for supplying the population [5], and its participation in hydrological processes. Over-fertilization causes insoluble nitrogen to percolate through the soil in the form of nitrate (NO_3) through leaching, infiltrating to the root zone, and reaching aquifers which would contaminate [6].

Thus, it is crucial to monitor the amount of fertilizer with a sensor in order to have a smart fertigation system. The IoT system, composed of different sensors placed in each three of the plots, was already described in [7]. In our system, we have different sort of sensors, including soil moisture, soil temperature, and soil humidity sensors. In addition, some sensors are included in the tube itself as the sensors presented in this paper. All the sensors will be wirelessly connected to a central Access Point (AP). The AP will receive the information and send it to an upper layer of the architecture to implement artificial intelligence techniques to define different rules to enhance its efficiency.

In this paper, we propose a conductivity sensor, based on a magnetic coil, which is capable of differentiating with great precision the changes of conductivity in a small range of salt concentration. Our proposal is ideal for monitoring the flow of fertilizers in irrigation water in a precise way using changes produced in the electromagnetic field produced by the developed coil. If the quantity of fertilizer increases in the irrigation water, the field produced by the sensor will be modified, bringing abrupt changes in the conductivity of the same varying the mS/cm. This is a very simple, but at the same time efficient way to obtain real-time data of what happens in the water destined for the fields and finally to control the over-fertilization of the fields, reducing the possibilities that the N of the soil contaminates the environment.

The rest of the paper will be structured as follows: Section 2 presents some related work where similar approaches are presented. Section 3 presents the architecture and sensors of our system. The results of our system are presented in Section 4. Finally, Section 5 details the conclusion and future work.

2 Related work

This section presents different related work focused on the water quality monitoring and the main drawbacks which cause that those solutions cannot be applied in our case.

H. Ramos et al. [8] developed and tested an in-situ conductivity sensor using cells for water quality monitoring. The sensor consists in three electrodes and two terminal devices. This system works by exchanging ions creating an electric field. When the water flow passes through this system, the electric field varies. This sensor works correctly although it depends largely on an anti-fouling coating, which despite being a very small amount. Also, this device is not suitable for continuous measurements in a closed space such as an irrigation pipe, maintaining a high precision in low salinity ranges.

L. Parra et al. [9] developed a conductivity sensor based on coils. A part of this is fed with a current at a specific frequency and voltage, creating a magnetic flux that induces the other part of the coil, thus creating a magnetic field. This field varies according to the presence of salts in the water and thus can be measured. This sensor has been tested in water with different concentrations of NaCl being a device with an optimal response for use in marine spaces. On the other hand, no experimental tests have been carried out with fertilizer and irrigation water, which is why this development is not suitable for use in agriculture.

W. Gong et al. [10] proposes a conductivity sensor based on two flat electrodes built on a PBC board. The author makes the measurements using KCI and water MQ. This sensor works at 334kHz obtaining significant variations in a wide range of salinity, suitable for marine environments. Although the device offers good results, it has not been tested in irrigation water with fertilizer, which represents completely different conditions to the one carried out in the experiment. Also, the cost presented is greater than what is wanted by a sensor of these characteristics, since it operates at a higher frequency than that used by our sensor.

L. Parra et al. [11] proposes the development of a low-cost wireless conductivity sensor to control freshwater flooding of lakes and mangrove reserves. The sensor used is composed of a toroidal coil and a solenoid, so that the first is fed by a sinusoidal wave and this induces the second. The results show a wide range of detection able to detect differences between small and large amounts of salt, typical of the sea. However, the need to detect fertilizer in the water requires a higher precision of the sensor in low concentrations, therefore this would not be optimal for this purpose.

There are many solutions to monitor conductivity in water. Nonetheless, no one of them has tested their sensors with fertilizers. In addition, we need a sensor which can measure in a low range of conductivities, to distinguish variations of fertilizers in water.

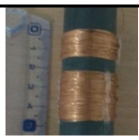
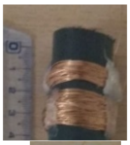
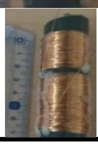
3 Proposal

In this section, we are going to describe the proposed prototypes to measure the concentration of fertilized and the proposed architecture of our IoT system.

Firstly, prototypes are described. They are shown in Table 1; all of them are created with copper wire with 0.4mm of diameter. The prototypes are coiled over a PVC tube with 25mm of diameter and 3mm of thickness. The differences between them are mainly the number of spires in the powered coil (PC) and induced coil (IC) and the distribution of the turns in different layers. Those characteristics can be seen in Table 1. The employed coils are based on the best results obtained by L. Parra et al. [12].

Our system is composed of different sort of sensors which are responsible for monitoring several parameters from the soil, the water, and the fertilizer. We have sensors monitoring the soil, which measures the moisture, the temperature, and the conductivity. The conductivity of the soil is related to the water quality used for irrigating and to the utilized fertilized. In addition, the quality of the water before adding the fertilizer is monitored considering the following parameters: temperature, conductivity, and turbidity. An Arduino sensor is selected to gather the data from the sensors, and it sends the information to an AP using WiFi technology. Once the data is received, the AP forwards it to a Database where AI is applied to determine the best way to fertigate the plants to enhance the sustainability of the fertigation process. This architecture and these sensors can be used in any sort of agriculture, which uses tubes to irrigate since the drip irrigation in orange trees to sprinklers in urban lawns.

Table 1. Characteristics of the prototypes.

Name	Picture	Coils	Name	Picture	Coils
P1		Spires: 40 PC, 80 IC Layers: 2	P5		Spires: 40 PC, 100 IC Layers: 1
P2		Spires: 40 PC, 80 IC Layers: 4	P6		Spires: 40 PC, 80 IC Layers: 1
P3		Spires: 40 PC, 80 IC Layers: 8	P7		Spires: 40 PC, 60 IC Layers: 1
P4		Spires: 80 PC, 160 IC Layers: 2	P8		Spires: 40 PC, 40 IC Layers: 1

4 Results

In this section, we going to show the results of different coils in NaCl. Secondly, we test with a fertilizer (Nitromagnesium 22(5)). Finally, we select the best prototype.

4.1 Tests with different prototypes

In this subsection, we show the tests with different prototypes with five samples which have different concentrations of table salt, also known as sodium chloride

(NaCl). The objective of this test is to find the working frequency (WF), it is to say, the frequency which has the maximum difference between samples of the prototypes.

For test the different prototypes we prepared 5 samples with a concentration of 0, 5, 10, 20, 35 and 45 g/l of NaCl. The conductivity of these samples is 0.37, 9.28, 16.21, 28.7, 48.5, and 60.3 mS/cm respectively (measured with an EC meter model Basic 30). The powered coil is connected to a wave generator model AFG1022 and the voltage of the IC is measured with an oscilloscope model TBS1104. The wave generator generates a sine wave of 3.3 peak-to-peak volts. Measurements are performed at frequencies from 10 to 1000 kHz each 10 kHz. In the PC, there is a resistance of 47 ohms in the positive cable placed in series. In the IC a capacitor of 10 nF in parallel is utilized.

The induced voltage (IV) in all the prototypes changes when the conductivity varies in all the frequencies tested. Therefore, it will be necessary to evaluate which will be the best prototype and the WF. To determine the WF of one prototype we must accomplish the following characteristics, (I) large difference in IV; (II) values can be adapted to a mathematical model; and (III) the IV follows the same trend in all samples. In Table 2 the WF and the difference of IV between 0 and 45 g/l of NaCl are presented.

Table 2. WF and IV variations for the models tested with NaCl

Prototype	WF (kHz)	IV variation (V)	Prototype	WF (kHz)	IV variation (V)
P1	140	3.67	P5	140	2.19
P2	110	-3.96	P6	160	1.56
P3	90	-6.58	P7	180	-5.36
P4	270	-1.76	P8	260	3.60

In Fig. 1 we can observe the values of IV for the different prototypes in their working frequency. All prototypes have a similar trend. They present a big change between the values 0 to 16.21 mS/cm. From this point, the IV reaches an upper limit and there are no more increments in the IV. In the prototypes P3 and P7, we can be observed a change in the trend compared to the other prototypes. Moreover, in prototypes P4 and P6, the difference between the dissimilar samples is small if we compared with the other prototypes. This causes a decrease in sensor sensitivity.

In this case, the best prototype is the P3. It has a large difference in the IV between the lowest and highest salinity and a good R^2 (0.9113) (R^2 is a statistic expression that indicates how the mathematical model adapted to the different points is). The mathematical equation that models the IV of prototype P3 is presented in Eq. 1.

$$Vout\ (V) = -0.003 \times Cond.\ (mS/cm) + 0.2352\ Cond.\ (mS/cm) + 8.0063 \tag{1}$$

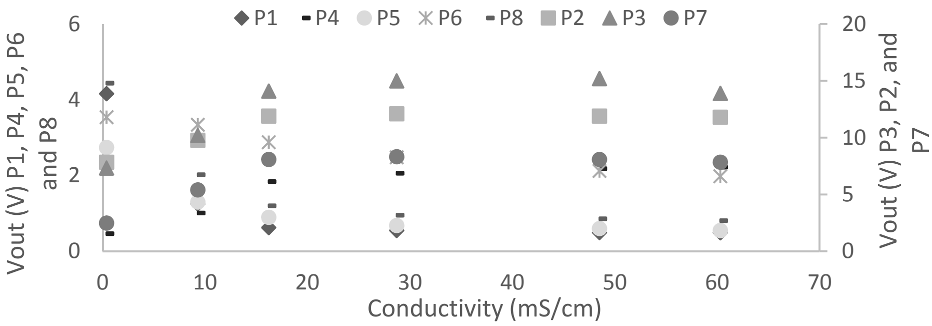


Fig 1. IV of the different prototypes in the best frequency with NaCl.

4.2 Calibration of selected prototypes

In this section, we show the effect in the coils when another salt causes the conductivity.

In this case, we prepared five samples with different amounts of fertilizer, Nitromagnesium 22(5) The used nitromagnesium has 22% nitrogen and 5% magnesium. Finding 11% of nitrogen in nitric form and the other 11% shaped likeammoniacal.. These samples are prepared with a concentration of 0, 5, 10, 20, 35, and 45 g/l of fertilizer. The conductivity of this samples is 0.37, 5.28, 10.03, 17.84, 28.6, and 36.5 mS/cm. Also, the values of conductivity are less than in the case of NaCl for two reasons. We use commercial nitromagnesium that contains a quantity of non-soluble matter so that the farmer can manipulate it. In addition, the electrical conductivity of each substance is different.

The values of IV in the different prototypes, in the same frequencies than we used before can be seen in Fig. 2. The coils behave differently if they are in the water with NaCl or with nitromagnesium. This indicates that the coils work differently depending on the diluted salt. In this case prototypes P5 and P7 presented and a low R^2 (0.6027 and 0.7299 respectively), for this reason, these models are not good for the monitoring of fertigation. In addition, the prototype P5 has a low voltage difference in the diverse samples. For this reason, this prototype is not useful for our purpose. The prototypes P6, P7, and P8 have a difference of 1.80, -2.43, 2.73 V. While the prototypes P1, P2 and P3 have differences of 3.56, -3.79, -4.95 V. These 6 prototypes adapt well to a mathematical model with high R^2 coefficients and have a good induced voltage difference between the samples. Therefore, we select the prototypes P1, P2, and P3 for its verification,We select these prototypes because are the prototypes that present more difference between the samples 0 and 45 g/l of nitromagnesium. That indicates that they will have a greater precision of the prototypes P6, P7 and P8.. Eq. 2, 3 and 4 is the mathematical model of P1, P2, and P3. These have an R^2 of 0.9417, 0.9735, and 0.9223 respectively.

$$Vout\ (V) = 2.1684 \times Cond.\ (mS/cm) - 0.405 \tag{2}$$

$$Vout\ (V) = 8.5715 \times Cond.^{.0915}\ (mS/cm) \tag{3}$$

$$Vout\ (V) = 1.3266 \times \ln(Cond.\ (mS/cm)) + 8.2649 \quad (4)$$

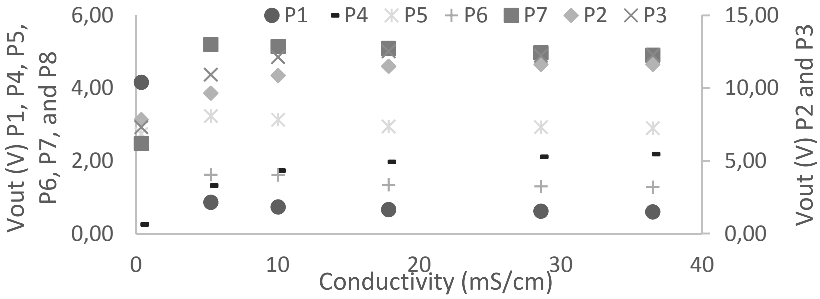


Fig 2. IV of the different prototypes in the best frequency with nitromagnesium.

4.3 Verification test

Finally, we are going to analyze the precision of the selected prototypes. For this test, we prepared different samples from 1 to 30 g/l with values from 1.99 to 24.6 mS/cm.

In Table 3, the values of IV, the values of the mathematical model, and the difference between these values are shown from different prototypes. The error is the difference between the real value and the value of the model. The relative error is error divided for real value and multiplied by 100. The prototype P2 has a lower relative error with an average error of 2.15%. For this reason, we selected this prototype as the best one.

Table 3. Verification of prototypes P1, P2 and P3

	Difference (V)			Difference (%)		
Conductivity (mS/cm)	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**
1.99	0.15	0.04	0.80	10.38	0.39	9.61
3.05	0.30	0.19	1.62	28.21	2.07	14.27
4.58	0.12	0.12	0.18	11.51	1.22	1.75
6.95	0.17	0.06	0.70	20.79	0.54	6.04
11.59	0.09	0.34	0.72	12.06	3.08	5.87
13.56	0.05	0.49	0.88	7.56	4.27	6.96
16.09	0.03	0.45	0.62	4.74	3.89	4.90
19.2	0.00	0.27	0.35	0.12	2.33	2.78
24.6	0.19	0.19	0.55	24.40	1.68	4.23
Average	0.11	0.24	0.64	13.06	2.15	5.62

5 Conclusion

Fertigation is a solution that allows irrigation to be managed in order to reduce the environmental problems of farming systems. In this article, we presented a new use of an existing sensor based on coils for fertigation monitoring.

We have determined the working frequency of the different prototypes with common salt. Our results indicate that the best prototype was the P3. Subsequently, we have tested the same with nitromagnesium, and the gathered data show different values than the data with the NaCl. It indicates that the coils can be more sensitive to different types of salts. In this case, the best models to work with the fertilizer were P1, P2, and P3. The P2 is the prototype that the smallest relative error during the verification test. In future work, we want to improve the sensitivity of our sensor and different salts.

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